



A Fully Automated Car Parking Lot

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ABSTRACT

Most car parking lots in the country have not been fully automated and many of them serve temporal, manual parking needs. A fully automated car parking lot assures of flexibility, improved efficiency and minimisation of manual tasks. In this paper, use was made of Siemens Step 7 PLC and WinCC Flexible Advanced software to design a fully automated car parking lot. The number of parking spaces available, the parking space number and position, arrival and departure times of cars and the time spent at the parking space are provided by the design. Simulations of designed system using Simatic PLC SIM confirmed the fulfillment of the design criteria and reliability of the developed flowcharts. Remote operator monitoring and control of the car parking lot has been actualised. Simulation results on the parking of six cars for a time duration of 0.5 hr, 1 hr, 1.5 hrs, 2 hrs, 2.5 hrs and 3 hrs, respectively yielded a total amount of GH¢ 17.00. It stands to reason that hitherto existing manual car parking lots should be converted into the fully automated type using a PLC and an HMI workstation in order to bring orderliness and deserving responsibility to car parking in Ghana.

INTRODUCTION

According to the U.S. Bureau of Transit/ Transportation statistics for the year of 2006, there are 250,851,833 registered passenger vehicles in the United States. These 251 million vehicles include cars, motor cycles, Sport Utility Vehicles (SUVs) and pick-up trucks. The New York Times magazine states that approximately a million passenger vehicles are introduced into the roads each year in the United States, which ultimately leads to a parking problem due to limited availability of spaces. A survey conducted by one of the car manufacturing companies, Bavarian Motor Works (BMW), shows that 20% of the inner traffic of major cities across a nation is in search of parking space. In Ghana, the well-known automated car parking lots are the Accra city car park, Ridge city car park, Accra and the Kotoka International Airport (KIA) car parks among others. The Accra city car park is Ghana's first multi-storey car park which is four storey with shops on the ground floor, two entry and exit electronic control barriers, two lifts and a parking space capacity for 500 cars. It started operations for both private and commercial drivers in the year 2000.

A car parking lot is a place for parking cars temporarily. It is found in most public places such as hospitals, business centres and hotels. Currently in Ghana, most car parking lots are conventional hence, are manually operated. The conventional car

parking systems very often employ human services to direct and ensure uniform car parking. This system is inconvenient in the sense that before parking, the number of parking spaces available, the parking space number and the physical position or direction to the parking space are not available to the user. Some negative effects of the manually operated car parking system usually for a one level car park are: Minor accidents such as scratching and peeling of paint and dents on cars when trying to park a vehicle between two other vehicles that have parked improperly; waste of land: more land space is required to accommodate greater number of cars; and waste of time and fuel to the driver. A fully automated car parking lot should provide for the minimisation of the inconveniences. It should be able to check the following before a car is allowed into the parking lot: The number of parking spaces available; the parking lot number; and the physical position or direction to the parking lot.

If the above conditions are satisfied and the system identifies a car at the parking lot entrance, the bar to the lot opens and allows the car in. The system checks the following before a car is allowed out of the parking lot: The system takes note of the time a car moves out of the parking lot. This will help to calculate the correct charge. When the car gets to the exit, the driver is shown the charge. The driver then pays the money into an electronic money detection machine; the system then checks the amount to be paid as against the amount put into the machine and performs further

calculations; and if all the above conditions are met, the exit bar opens and the number of parking lots available increases by one. This information need be available on a defined screen whether a car is coming into the parking lot or not. Finally, there should be remote monitoring of the entire fully automated car parking lot. A Programmable Logic Controller (PLC) capably withstands noise and vibration and it is purposed for industrial environments to replace relay-contactor based sequencing subsystems in manufacturing and allied processes. Research on PLC-based automation as a better alternative to hard-wired control was conducted by authors in [1]. The PLC has wide applications in automation, such as in a protomatic labeller of a brewery [2], Automated Guided Vehicle (AGV) using a Kalman filter algorithm based on memorised path and kinematics determination of vehicle movement [3], management and control of distributed renewable energy production units for minimum specific fuel consumption in real time [4], energy management and energy optimisation in the process industry [5], manufacturing process of the glue and gritting of aluminum helical wires [6] and vacuum controls [7].

Related works on automated car parking systems have been duly reported in the literature. Authors in [8] designed and implemented a digital parking lot management system that uses Radio Frequency Identification (RFID) technology. The system enhances the utilisation of parking space and helps users check the availability of the parking space remotely as the system is connected to the Internet. The project implementation was in four stages as follows: embedding the code into a tag and assigning the same to a car; reading the data from the RFID tag to the microcontroller; data is uploaded from microcontroller to the ethernet network; keep a track of vacancies of the parking spaces. An automatic car parking system using Personal Computer (PC), National Instrument's Data Acquisition (DAQ) card and LabVIEW software package was developed by authors in [9]. The quantities of any physical system to be automated are sensed by the sensors and converted into electrical signals by suitable transducers and signal conditioners. A computer program was developed to receive the signals from the transducers through the DAQ card, process the signals and send the output signals to the protective devices or equipment/machinery to be controlled. In [10], authors designed a fully automatic, five rupee coin operated car parking system for installation in shopping malls and supermarkets. A novel mechanical design had been used which identifies the impact force of the object dropped from a specific height, thereby operating a lever to swing to give a signal to the electronic system. The electronic system is designed to detect the presence or absence of a car in a particular spot by infrared transmitter and receiver system. For every five rupee coin dropped, there is a fixed time allotted. The time of parking allowed can be extended by dropping multiple coins. An intelligent car park management system based on wireless sensor networks was proposed by authors in [11]. It uses wireless sensors deployed in the parking lot to detect and monitor the occupancy of the parking lot. In [12], researchers automated a manually operated underground cable pulling winching machine using PLC where they replaced all mechanical functions with electrical controls operated via HMI. Speed, length and tension of the winded rope are displayed by the HMI.

Authors in [13] reviewed fifteen papers on vacant parking slot detection and tracking. An interface and a software/hardware module for an intelligent car parking management system on FPGA was provided by the authors of [14] whilst Kaur and Singh [15] designed and tested an FPGA-based car parking system and implemented it using Finite State Machine (FSM) HDL modelling. In a graduation project, authors in [16] developed an automated mechanised rotary car parking system using LS-XBG PLC and Atmega328 on Arduino Uno board for condensed urban areas. Iyaka in [17] presented a prototype of a smart parking system to be used in a university, shopping mall and nearby packing areas. Parking slot availability and booking for reservation are two great features of the android-based smart parking system. A 3-mode solar-powered, automatic intelligent 6-car parking system that ensures driver safety and saves both time and parking spaces using SIMATIC S7-300 PLC was designed and implemented by Islam *et al.* [18] and Sonar *et al.* [19] implemented a prototype automatic underground car parking system suitable for congested cities using a PIC microcontroller, DC motor and sensors. Authors in [20] designed and developed an automatic integrated car parking system using RFID technology, infrared sensors, GSM, 78052 microcontroller and LED (for empty slot indication). Meanwhile, in [21] a smart car parking system based on RFID code tracking was developed whereby each car had an RFID tag on it and each parking space had an RFID reader. A pattern rule generation concept was utilised for car space allocation.

This paper seeks to design an automated car parking lot using Siemens PLC; design a proper means of controlling the movement of cars in and out of the parking lot and making this information available on an HMI workstation; and design a control system for the parking lot to ensure that the maximum capacity is not exceeded.

METHOD

Design Concept and Criteria

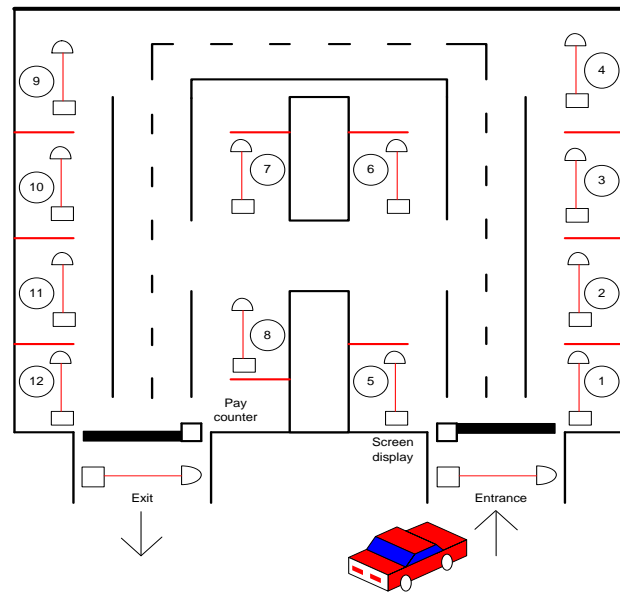
Schematic diagram of the proposed fully automated car parking lot is as shown in Fig. 1. The road serves as a driveway in and out of the parking spaces. The blockade acts as a parking lot barrier. The parking space number is meant for the identification of parking spaces. There are twelve parking spaces for the purpose of demonstration. The barrier gate controls the parking lot accessibility. The retro-reflective sensor generates and sends information to the PLC. These sensors are provided at the car parking spaces, the exit and the entrance points.

Mode of Operation of the Proposed Automated Car Parking Lot

There are four operative stages of the automated car parking lot.

Car at the parking lot: Position car within the demarcated area. The sensor senses the presence of a car and sends a signal to the PLC. The PLC searches through the program and a corresponding output is released. The program searches for empty car parking spaces. For example, three parking spaces are found, that is, parking spaces 1, 3 and 5. Display parking spaces 1, 3, 5 on LED

display. The LED display is fixed on the wall beside the driver. The entrance barrier gate opens and this stage takes about 5 seconds.



Legend

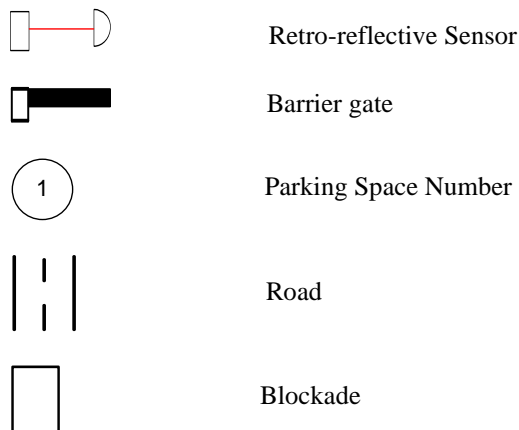


Fig. 1 Schematic Diagram of the Proposed Fully Automated Car Parking Lot

Car at the parking space: There are two sub-stages at the car parking space namely, “car packed” and “car removed”. For car parked, the sensor senses the presence of the car and sends information to the PLC. The PLC searches through its program. The corresponding output under satisfied conditions will start a timer. For the car removed: The same sensor sends information to the PLC. The timer stops because the car has been removed. Difference in time is calculated and the time spent is converted to corresponding money equivalent. Information is conveyed to the cash counter.

Car at the Exit: Park car near the cash counter. Pay money into cash counter machine; wait for change or top up amount. Feedback is sent to the PLC. The PLC makes decisions based on the program and the barrier gate is opened. Car exits the car parking lot.

Monitoring: Monitoring is done remotely where the PLC program is integrated with Simatic WinCC Flexible HMI Advanced workstation. Fig. 2 shows the flowchart for the first three operating stages of the automated car parking lot.

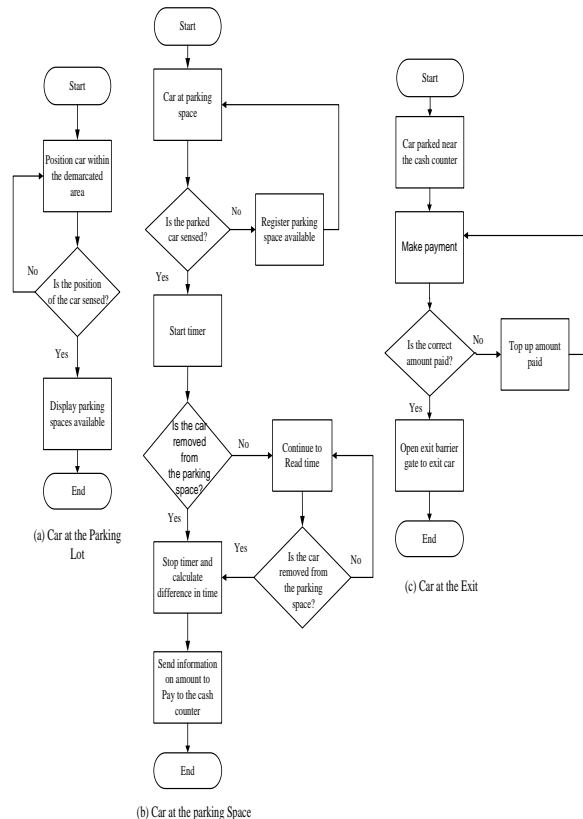


Fig. 2 Flowcharts for the Operating Stages of the Automated Car Parking Lot

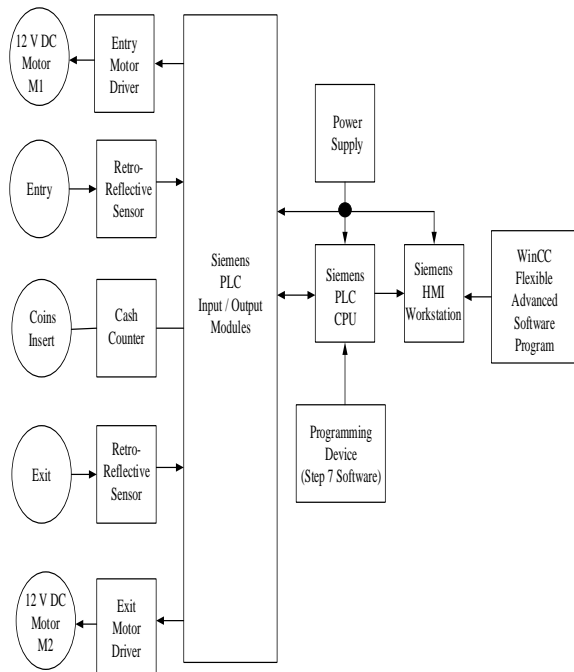


Fig. 3 Block Diagram of the Proposed Fully Automated Car Parking Lot

Proposed Design Implementation of the Automated Car Parking Lot

Fig. 3 shows the block diagram of the proposed design implementation of the automated car parking lot. The design makes use of Siemens PLC and HMI workstation, Siemens Simatic Step 7 PLC programming software and a programming device. The design criteria for the automated car parking lot are as follows:

- (a) The system should be programmable and reprogrammable using Siemens Simatic Step 7 PLC programming software;
- (b) It should have an HMI workstation facility for the real time display of events;
- (c) Design should be compatible with most of the existing car parking lots in Ghana;
- (d) The entrance barrier gate should open steadily to prevent any accidents;
- (e) The screen should be positioned on the driver's side for easy view;
- (f) The process must be fast and not time consuming; and
- (g) The design should give the car's arrival time, departure time and the time spent at the parking space.

Materials

Automated Car Parking Lot Hardware

Entrance and exit barrier gates: The barrier gates consist of a long metallic single-arm, which blocks a vehicle from moving forward. It is programmed to lift automatically when a sensor detects that a vehicle is waiting to pass through the gate. There is also a mechanism that causes the gate arm to go back up if a vehicle does not move in time, preventing damage to the vehicle. The barrier gates prevent motor vehicles from entering and exiting the closed parking lot.

Retro-reflective sensor: A total of 14 retro-reflective sensors are employed in the individual parking spaces and the entrance and exit gates. Each sensor contains an emitter and a receiver element that establishes an effective beam between the emitter, the reflector and the receiver. The sensor functions when an object interrupts or breaks the effective beam. The sensor communicates the activities of the parking lot to the PLC.

Cash counter: At the time of leaving the car park, the parking charge is required to be displayed. A cash counter is required at a convenient place to pay the parking charge by the user. Liquid Crystal Display (LCD) with a coin separator has been placed at the exit gate to count the number of coins of different denominations. The cash counter uses the size of the coins to determine coin denomination. The coin is placed in a 'coins insert' opening at the top of the counter. There is a slant on which the coins slide down. The first hole built into the slant is a 5, 10, 20, 50-pesewa hole. The measure of how many coins are in each slot is determined by the weight of the coins using a scale. This determines the value of the coins inserted. The cash counter sends the information to a processing unit, which displays the total value.

12 V DC motor and driver circuit: Two 12 V DC reversible motors with shaft-mounted bars control the opening and closing of the barrier gates at the entrance and exit gates. The barrier gate is controlled through a computer program that sends electrical signals to a motor driver. The motor driver sends pulsed voltages to the 12 V DC motor in order to accurately move the barrier gate to a predetermined location for the vehicle to move past. The 12 V DC motors are given the needed forward and reverse motions by a four 1N5817 Schottky diode-based H-bridge driver circuit at a specified speed.

Siemens PLC: The PLC is a hardware that communicates with the field devices. It is also the PLC that does the job of the program software. The Siemens S7-300 PLC package used consists of the 315- 2AG10-OABO CPU, the SM 321 DI 32 × DC 24 V input modules and the SM 322 DO 16 × DC 24 V/0.5 A output modules. The PLC is housed in a control panel located close to the automated car parking lot. The PLC-equipped control functions include the emergency stop and start buttons. An 80 Gb hard disk, 4 Gb RAM laptop is used as the programming device to program the Siemens PLC.

HMI workstation: The HMI workstation used is a computer on a network, where the human operator has access to everything on the entire network. The HMI workstation in the remote control room enables the human operator to monitor and supervise the operation of the automated car parking lot. It enables the operator to visually interpret any situation at the automated car parking lot.

Power supply: The PLC and the HMI workstation are powered from a 24 V DC power supply obtained from AC and DC networks, 1-phase and 3-phase supplies.

Automated Car Parking Lot Software

Siemens step 7 programming software: Step 7 is the standard software package used for configuring and programming Simatic PLCs. The Step 7 software is supportive in all phases of the creation process of the automation task such as: setting up and managing projects, configuring and assigning parameters to hardware and communications, managing symbols, creating programs among others.

WinCC flexible advanced software: Simatic WinCC Flexible Advanced software is ideal for use as the HMI software in all applications in which operator control and monitoring is required either on site or close to site.

Methodology

Flowchart of the Automated Car Parking Lot

A system flowchart was developed thus enabling the writing of codes based on programming stages with the help of the process signals. Fig. 4 shows the system flowchart for the proposed automated car parking lot.

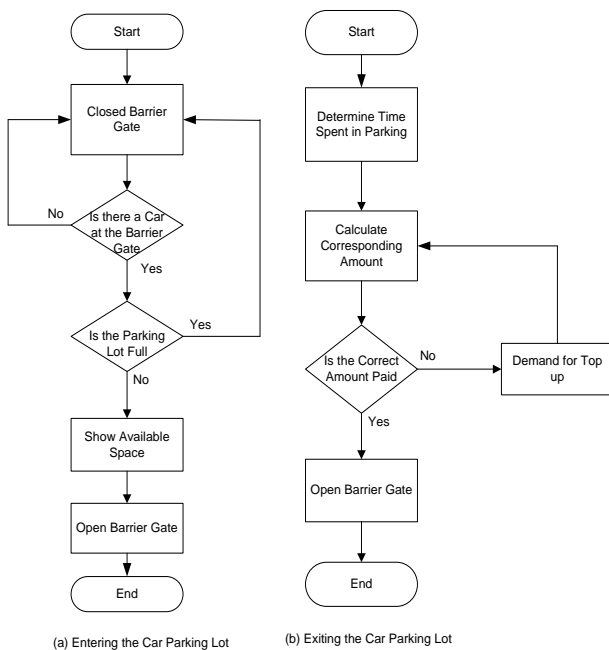


Fig. 4 The System Flowchart of the Proposed Fully Automated Car Parking Lot

Programming the Automated Car Parking Lot

Programming of the automated car parking lot starts with creating a project in Siemens Step 7 Simatic Manager. The project created is named AUTO_CAR_PARK. It is a folder which stores the entire main programming work done in Step 7 Simatic Manager for the automated car parking lot. The main work is made up of two stations namely SIMATIC 300 station and Simatic HMI station. The Simatic 300 station was configured and using the hardware configuration tool in Simatic Manager, the physical PLC hardware arrangement got configured. Fig. 5 depicts the hardware configuration. The Step 7 software was used to effect the PLC programming. The program consists of blocks and symbols. The blocks represent the program codes and the symbols represent the process signals. The software development was based on the system flowchart. In all, there are a total of 30 input and 6 output signals for a car park having 26 parking spaces. A 32-channel input card “DI 32 × DC 24V; 321-1BL00 - 0AA0” is selected since there are 30 inputs to the PLC. A 16-channel output card is required. The empty channels are reserved for future expansion. The output signals from the PLC are defined as:

- Q0.0 – Inlet motor run command open
- Q0.1 – Inlet motor run command close
- Q0.2 – Exit motor run command open
- Q0.3 – Exit motor run command close
- Q0.4 – Payment made signal
- Q0.5 – Car exiting signal
- Q0.6 – No comment
- Q0.7 – No comment

Fig. 6 is the symbol editor table showing the signal symbols and addresses of the proposed design. The SIMATIC HMI station forms part of the soft - hardware devices used. Software program used for the HMI station is the WinCC Flexible Advanced. Fig. 7 shows the summary of the AUTO_CAR_PARK project window.

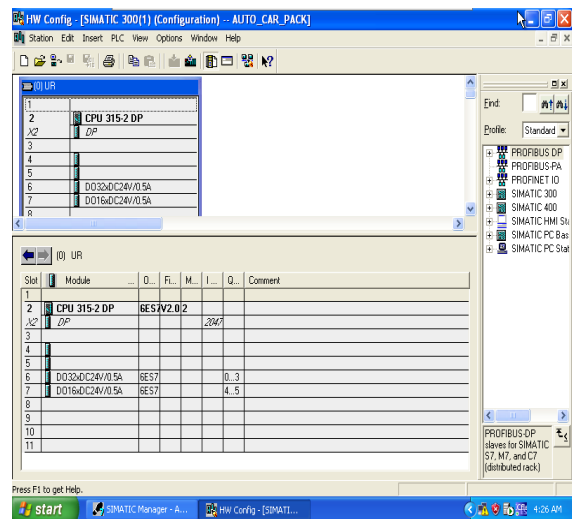


Fig. 5 A Print Screen Of Hardware Configuration Window

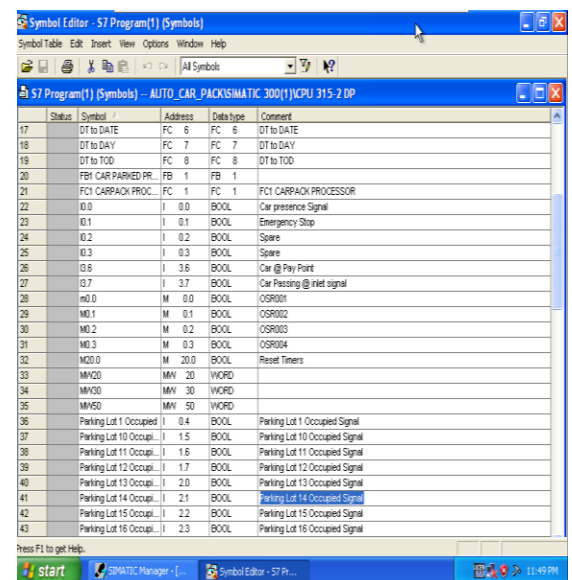


Fig. 6 A Print Screen of Window of the Symbol Editor

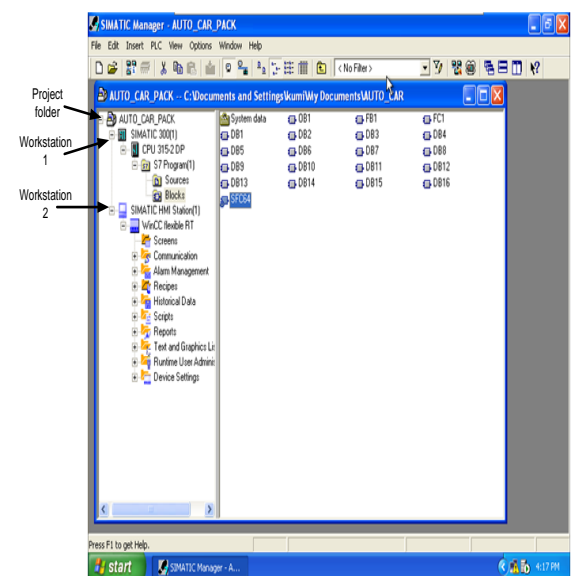


Fig. 7 Summary of the AUTO_CAR_PARK Project Window

The codes for the design of the programming blocks were written in ladder logic and function block diagram programming languages. The program codes can be found in the S7 program under the program blocks. The programming languages were chosen from the S7 program. Fig. 8 and Fig. 9 show the program block OB (1) and DB (1), respectively in Ladder Logic Diagram (LAD) programming language. Fig. 10 and Fig.11 show the program blocks FC (1) and FB (1), respectively in Function Block Diagrams (FBDs).

RESULTS AND DISCUSSION

Design Features

The following features (Table 1) provide basic information on the automated car parking lot to the operator in a remote control room.

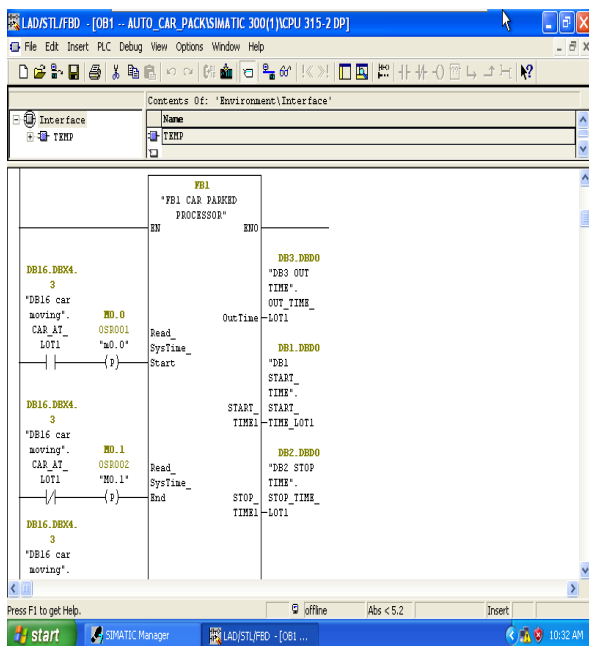


Fig. 8 Organisational Block OB (1)

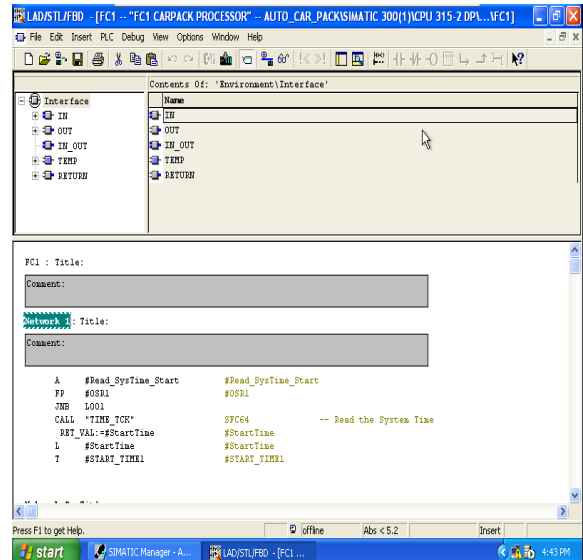


Fig. 10 Function FC (1)

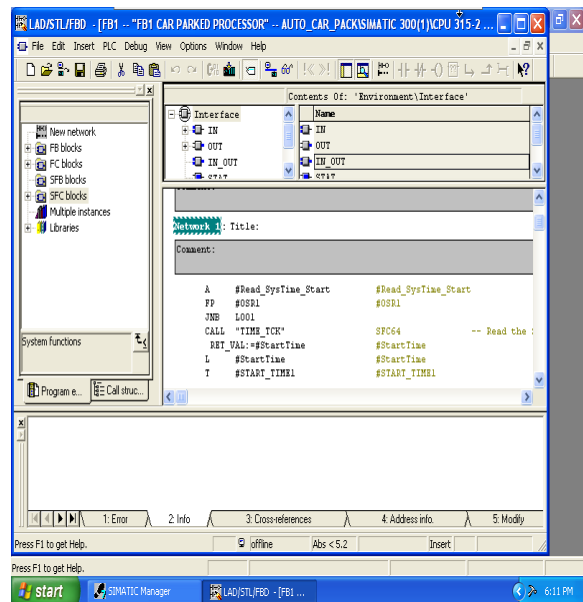


Fig. 11 Function Block FB (1)

Address	Name	Type	Initial value	Comment
0.0	START_TIME_LOT1	TIME	T#0MS	
+0.0	START_TIME_LOT2	TIME	T#0MS	
+4.0	START_TIME_LOT3	TIME	T#0MS	
+8.0	START_TIME_LOT4	TIME	T#0MS	
+12.0	START_TIME_LOT5	TIME	T#0MS	
+16.0	START_TIME_LOT6	TIME	T#0MS	
+20.0	START_TIME_LOT7	TIME	T#0MS	
+24.0	START_TIME_LOT8	TIME	T#0MS	
+28.0	START_TIME_LOT9	TIME	T#0MS	
+32.0	END_STRUCT	END_STRUCT		

Fig. 9 Data Block DB (1)

Table 1 The Design Features and their Functions

Design Feature	Function
Arrival time	Shows the arrival time of the car at a specified parking lot
Departure time	Shows the departure time of the car at a specified parking lot
Time spent	Shows the total time spent at a parking lot by calculating the difference in time between the arrival and departure time.
Parking lot sensor (represented by a box)	Displays continuous blinking of the colours red and yellow when the parking lot is empty and displays the colour green when the parking lot is occupied.
Barrier gate	Opens and closes when a car is entering or leaving the parking lot
Function keys	Shortcut keys for performing certain functions

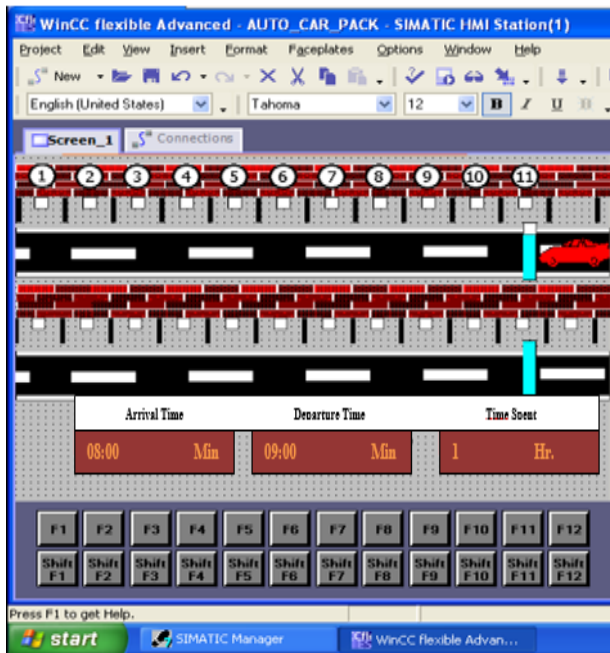


Fig. 12 The Design Interface Simulation in Wincc Flexible Advanced Runtime

Table 2 Summary of Results

Item	Arrival Time (Hours)	Departure Time (Hours)	Time Spent (Hours)	Amount Paid (GH ¢)
1	08:00	08:30	0.5	2.00
2	08:00	09:00	1	2.00
3	09:00	10:30	1.5	2.50
4	09:00	11:00	2	3.00
5	10:00	12:30	2.5	3.50
6	10:00	13:00	3	4.00

Table 3 Cost Analysis

Item	Quantity	Unit Price (GH¢)	Cost Price (GH¢)
Retro-reflective Sensor	26	500.00	13000.00
Barrier Gate	2	500.00	1000.00
Siemens PLC	1	2150.00	2150.00
Personal Computer (PC)	1	1000.00	1000.00
12 V DC Motor	2	670.00	1340.00
H-Bridge DC Motor Driver	2	137.00	274.00
Cash Counter	1	160.00	160.00
Estimated Labour Cost	1	2000.00	2000.00
Total Cost (GH¢) = 20,924.00			

Real – Time Simulation Results

Simulation of the Step 7 Siemens PLC program without physical hardware was conducted using the SIMATIC PLC SIM which is very appropriate for programs with not very large I/O. Fig. 12 shows the design interface simulation opened in WinCC Flexible Advanced runtime. A summary of results for six cars that parked at the automated car parking lot is presented in Table 2. Up to an hour of parking time attracts a monetary charge of GH¢ 2.00. Subsequent 30 minutes attracts GH¢ 0.5. Table 3 gives the cost analysis of the design for 26 parking spaces. The unit prices of components are as indicated [22; 23; 24].

Discussion

In terms of performance, the programming codes were able to perform the set objectives of the automated car parking lot. The SIMATIC HMI station is seen to be simple and user friendly. The programming codes can be easily fashioned to accommodate future adjustments. Troubleshooting can be done without much difficulty since the program code can be re-visited and reprogrammed. The use of 12 V DC reversible motor and the barrier gates brings the design closer to the hitherto existing manual parking lots in the country.

CONCLUSIONS

An automated car parking lot has been successfully designed using Siemens PLC and HMI workstation with simulation of the design conducted using SIMATIC PLC SIM. By the design, the operator controls and monitors the operation of the automated car parking lot from a remote area. With the use of retro-reflective sensors, a programmable and reprogrammable Siemens Simatic Step 7 PLC and an HMI workstation facility positioned on the driver's side for easy view for the real time display of events in terms of arrival and departure times of cars, the time spent at the parking space, the automated payment facility as well as information on parking spaces available, a fully automated car parking lot has been achieved. HMI workstation operator controls the facility from a remote control room. Writing of the control program using ladder logic and function block diagrams facilitated simplicity and ease of use. The designed system will be useful to companies, both large and small, that require car parking services. Conventional car parking systems should be converted into fully automated systems using a PLC and HMI workstation

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